Three-dimensional computer-assisted corrective osteotomy with a patient-specific surgical guide for an antebrachial limb deformity in two dogs

Longo, Francesco ; Penelas, Alexandra ; Gutbrod, Andreas ; Pozzi, Antonio

Abstract: We describe patient-specific surgical guide prototyping and surgical treatment of a complex antebrachial deformity in two skeletally mature dogs presenting with chronic lameness. Computer-assisted surgery was elected to increase accuracy in the correction of the complexity deformity. Radiographs and CT scans revealed a biplane deformity with valgus, procurvatum and external torsion of the right radius in both cases. The pre-surgical planning started from the quantification of the angular deformity, computer simulated correction to end up with a rehearsal surgery on 3D printed bone models. During the surgery, the custom-made osteotomy guides closely fitted the bone, allowing for a precise corrective osteotomy, that was stabilized with two locking plates. Postoperative x-rays showed successful correction of the deformity. At the follow up recheck examinations at 8 and 12 weeks postoperatively the dogs had improved lameness, weight-bearing and progression of bone healing were observed in both dogs. Patient-specific surgical guides allowed for a satisfactory correction of the antebrachial deformity. Additional benefits of using customized surgical devices include standardization and reduced surgical time.

DOI: https://doi.org/10.17236/sat00216

Other titles: Dreidimensionale computerunterstützte Korrekturosteotomie mit einer patientenspezifischen chirurgischen Schablone bei zwei Hunden mit antebrachiellen Deformitäten

Originally published at:
Longo, Francesco; Penelas, Alexandra; Gutbrod, Andreas; Pozzi, Antonio (2019). Three-dimensional computer-assisted corrective osteotomy with a patient-specific surgical guide for an antebrachial limb deformity in two dogs. Schweizer Archiv für Tierheilkunde, 161(7/8):473-479.
DOI: https://doi.org/10.17236/sat00216

THREE-DIMENSIONAL COMPUTER-ASSISTED CORRECTIVE OSTEOTOMY WITH A PATIENT-SPECIFIC SURGICAL GUIDE FOR AN ANTEBRACHIAL LIMB DEFORMITY IN TWO DOGS

Federico Longo, Alexandra Penelas, Andreas Gutbrod, Antonio Pozzi

Department of Small Animal Surgery, Vetsuisse Faculty University of Zurich, Winterthurerstrasse 260, 8057 Zurich, Switzerland

Corresponding author: Federico Longo, flongo@vetclinics.uzh.ch, +44 78 255 42 87
Department of Small Animal Surgery, Vetsuisse Faculty University of Zurich, Winterthurerstrasse 260, 8057 Zurich, Switzerland

Summary

We describe patient-specific surgical guide prototyping and surgical treatment of a complex antebrachial deformity in two skeletally mature dogs presenting with chronic lameness. Computer-assisted surgery was elected to increase accuracy in the correction of the complexity deformity. Radiographs and CT scans revealed a biplane deformity with valgus, procurvatum and external torsion of the right radius in both cases. The pre-surgical planning started from the quantification of the angular deformity, computer simulated correction to end up with a rehearsal surgery on 3D printed bone models. During the surgery, the custom-made osteotomy guides closely fitted the bone, allowing for a precise corrective osteotomy, that was stabilized with two locking plates. Postoperative x-rays showed successful correction of the deformity. At the follow up recheck examinations at 8 and 12 weeks postoperatively the dogs had improved lameness, weight-bearing and progression of bone healing were observed in both dogs.

Patient-specific surgical guides allowed for a satisfactory correction of the antebrachial deformity. Additional benefits of using customized surgical devices include standardization and reduced surgical time.

Key words

Bone deformity, computer-assisted surgery, dogs, patient specific surgical guides, rehearsal surgery

Zusammenfassung

Der Bericht beschreibt den Prototyp eines patientenspezifischen chirurgischen Guides mit dessen Hilfe bei zwei ausgewachsenen Hunden mit chronischer Lahmheit die chirurgische Versorgung einer komplexen Unterarmdeformität durchgeführt werden konnte. Aufgrund der Komplexität der Knochendeformation und der geplanten Operation wurde eine computerassistierte Chirurgie gewählt. Sowohl die Röntgenbilder als auch die CT-Studien zeigten biplanare Deformitäten mit Valgus, Prokurvatum und Aussenrotation des rechten Radius auf. Die präoperative Planung beinhaltete die Quantifizierung der Deformität, die Computersimulation der Korrekturosteotomie und die Durchführung der Operation an 3D gedruckten Knochenmodellen. Die spezialangefertigten Osteotomie-Guides wiesen intraoperativ eine akkurate Knochenanpassung auf, welche präzise Korrekturosteotomien erlaubten. Die Osteotomien wurden mit zwei Verriegelungsplatten stabilisiert. Die postoperativen Röntgenbilder zeigten in beiden Fällen eine gelungene Korrektur der vorangegangenen Deformitäten. Die klinischen und röntgenologischen Kontrollen nach 8 und 12 Wochen wiesen eine abnehmende Lahmheit, zunehmende Gewichtsbelastung und progressive Knochenheilung bei beiden Hunden nach. Die Patientenspezifischen chirurgischen Guides erlaubten akkurate Osteotomien und Korrekturen der Unterarmdeformitäten. Eine zusätzlicher Nutzen solcher spezifisch angepassten chirurgischen Vorrichtungen ist eine mögliche Standardisierung und eine Verkürzung der Operationszeit.

Schlüsselwörter

Knochendeformation, Computerassistierte Chirurgie, Hund, patientenspezifische chirurgische Guides, Testoperation

Introduction

Bone deformities of the antebrachium represent the most frequent form of angular deformity in dogs[7] and often need corrective osteotomy to be treated appropriately [6,15]. To achieve this goal, an accurate study of the bone alterations based on center of rotation of angulation (CORA) methodology is imperative[15]. Preoperative planning for antebrachial deformity has been described based on orthogonal radiographs [3,6]. However, advancements within the orthopedic field have introduced three-dimensional (3D) imaging techniques such as computed tomography (CT) [14] and computer-aided-design (CAD) software [8,16] to enhance visualization of bone models. The acceptance of computed-based technology has strongly encouraged the customization and surgical use of 3D printed guides to aid surgeons intraoperatively[1].

The present case report describes the design, prototyping and surgical application of 3D custom-made guides, which were used as computer-assisted devices to treat a biplane bone deformity of the antebrachium in two dogs.

Case report

Two castrated male dogs were referred to the Small Animal Hospital of the University of Zurich for a chronic lameness on the right front limb.

Case 1 was a 7 years-old, mixed-breed dog, weighing 19.1 kg. On visual examination, the dog exhibited a 2/4° front right lameness. Radial procurvatum, valgus as well as external torsion of the distal right front limb were visible. At physical palpation, moderate atrophy of the antebrachial muscles, mild reduction of the range of motion (ROM) of the right elbow and painful carpal flexion were found. An orthogonal radiographic study (Fig. 1a), followed by a CT examination of the front limbs, showed mild incongruence of the right elbow joint, shortening of the ulna, proximal displacement of the radial styloid process, valgus and torsional deformities in the right antebrachium.

Case 2 was 3 years-old Shih Tzu of 3 kg. On visual examination, a 2/4° front right lameness was noted along with the presence of radial procurvatum, valgus and external torsion of the paw. The physical examination revealed mild atrophy of antebrachial musculature with diminished and painful ROM of the elbow. Radiographic and tomographic findings (Fig. 1d) confirmed the clinical findings, showing an elbow incongruence with severe shortening of the ulna, presence of a large intra-articular fragment compatible with a fragmentation of medial coronoid process, radial head subluxation and flattening of the ulnar trochlear notch.

Computer Assisted Preoperative Planning

The preoperative planning was carried out with the assistance of an engineering company (IRPD, St. Gallen, Switzerland) and consisted of four steps:

1- The anatomical proximal and distal radial angles were measured on craniocaudal and mediolateral radiographs of the affected radius. On the craniocaudal view, the anatomic medial proximal radius angle (aMPRA) measured 69° (case 1) and 53° (case 2), while the lateral distal radius angle (aLDRA) was 78° and 76° respectively. On mediolateral view, the anatomic proximal caudal radius angle (aCdPRA) measured 99° (case 1) and 122° (case 2); while the distal caudal radius angles (aCdDRA) was 58° and 75° respectively. The magnitude of CORA was for case 1: 28° valgus and 34° procurvatum and for case 2: 15° valgus and 31° procurvatum.

2- The right antebrachium was segmented with a commercially available DICOM software (Osirix, Pixmeo, Switzerland) and a stereolithographic (STL) file was created to obtain a 3D surface bone model. The STL file was imported in a CAD software where it was elaborated. A computer-simulated correction was performed. A closing wedge was removed from the medial and cranial radial cortices, based on either the quantification of the deformity or the CORA location. The bones were then digitally aligned in a new position, reaching parallelism between proximal and distal joint reference lines (Fig. 2a,b). The new antebrachial positioning was compared to the starting bone alignment (mirror image function).

3- The osteotomy guide was set up on the basis of the quantification of the closing wedge and on the profile of the dorsal radius. This custom-made surgical device was designed to have two osteotomy slits functioning as plane guides: the angle of intersection of the two osteotomy slits was equivalent to the magnitude of the CORA. The printed guide included two holes with a co-planar orientation on both sides to temporary fix the guide on bone through K-wires (Fig. 3a,b).

4- The osteotomy guide was prototyped and manufactured in a true to real scale with a material that could be sterilized and shaped in surgery (Polyamid 12). Several bone models (Polylactic acid) of the affected antebrachia were 3D printed (Drukarka 3D, 3D Gence SP., Poland) to perform a rehearsal surgery. During the rehearsal corrective osteotomy, the fitting and shaping of the osteotomy guide on the radial cortex as well as the feasibility of deformity correction were checked. Locking plates (ALPS, Kyon, Zurich) were contoured to fix the bone fragments and then sterilized for the surgery.

Surgery

A cranial approach to the radius was performed, extending the skin incision from the radial diaphysis to the carpal joint. The custom-made osteotomy guide was positioned on the radius and temporarily fixed with four 1mm K-wires (Fig 4a). A closing wedge osteotomy of the radius was executed with an oscillating saw by aligning the saw blade with the osteotomy slits (Fig. 4b). A lateral approach to the ulna was made through a skin incision from the ulnar styloid to the midshaft. An ulnar ostectomy was performed. The osteotomy guide was removed, and external torsion was corrected intraoperatively aligning the carpus to the elbow. The correction of the valgus and procurvatum deformities was achieved by aligning the radial fragments with bone reduction forceps (Fig. 4c). The pre-contoured locking plates (ALPS 8 and 6.5) were fixed on the craniolateral and medial cortex of the radius using locking and cortical screws (Fig. 4d). To promote bone healing, autogenous cancellous bone graft was collected from the proximal humerus and packed around the radius osteotomy and ulnar gap. The surgical wound was closed routinely.

Orthogonal postoperative radiographs showed a correct implant positioning and an improved antebrachial alignment (Fig. 1b, e). Cage rest was recommended for 6-8 weeks. Activity was restricted to ten minutes walking with 2-3 times per day and gradually increased until complete bone healing. Radiographs rechecks were planned at 4, 8, and 12 weeks.

Follow-up examination

Case 1 significantly improved at the 4-week recheck examination. A minimal lameness (1/4°) along with mild painful carpal palpation and reduced carpal ROM in flexion were noticed. Recheck radiographs showed loosening of the proximal locking screw of the cranial-medial plate, and thus the screw was removed. At the 8-weeks recheck the weight bearing of the operated limb improved and the radiographs showed a progressive new bone formation at the osteotomy sites (Fig.1 c). The osteotomy was completely healed at the 12 week-recheck. A second proximal locking screw of the craniomedial plate was loose and therefore removed. At 1-year recheck examination the dog showed no lameness with an improved and pain free carpal ROM.

Case 2 improved at the 4-week recheck examination, but still presented a 2/4° right front limb lameness and moderate painful elbow palpation. Radiographs showed an advanced healing of the radial osteotomy as well as a decreased radio-ulnar step with moderate osteophytosis in the cranial aspect of the radial head. At 8 and 12-weeks rechecks new bone formation was found with an increased radiopacity in the radius and solid new callus formation in the ulna gap. A mild radiolucency surrounding one distal and two proximal screws was noticed, therefore these screws were removed (Fig.1 f). At the final 16-weeks recheck the dog exhibited a 1/4° right front limb lameness. At palpation an increased antebrachial muscular tone and a mild painful ROM of the right elbow were found.

Discussion

We found that the computer-assisted corrective osteotomy allowed a correction of the deformity with a simple intraoperative execution of the preoperative planning. The application of the osteotomy guides to the distal radius was facilitated by the profile adjusted to the true-sized bone model derived from CT images. As a result, no time was spent in manually finding the planned osteotomy site. We found that the custom-made osteotomy guides closely fitted the bone without extensive soft tissue dissection. Furthermore, neither use of additional joint-oriented K-wires nor fluoroscopy were needed. Both patients had a positive clinical outcome with an improved limb use. Despite the strong fixation provided by the double plate technique, we had some minor implant-related complications, which were easily managed and did not compromise the success of the surgeries. We opted for using a double plate fixation, based on the complex biplane nature of the deformity. In addition, the use of two smaller plates rather than a single large implant may decrease the impingement between implant and extensor tendons.

Advantages of computer-assisted surgical techniques involve both preoperative and intraoperative phases of corrective osteotomies. First, CAD software enables the user to manipulate the bone model, design bone wedges and detect the planes of the articular surfaces [13]. A mirror imaging function is available to superimpose the affected region on either the original alignment of the bone or the contralateral reference limb, enabling a precise deformity correction. Second, rehearsal surgeries could be performed on 3D printed bone models, allowing to test the guides before the surgery [9, 12]. The rehearsal surgery was useful because we slightly modified the printed guides to improve the fitting on the radius and adjust the angle of the osteotomies. Additionally, we were able to pre-contour all the implants, without the need of intraoperative modifications and, thus, decreasing the surgical time. Third, performing a free-hand osteotomy may potentially lead to errors. The patient-specific osteotomy guides act as precise intraoperative localizers of the CORA and provide a controlled guidance during the osteotomy. Therefore, we may speculate that these devices could be helpful for surgeons who are at the initial learning curve for the treatment of such complex bone deformities.

The potential drawbacks of computer assisted surgery are the cost and the time required to plan and print the osteotomy guides. The time for performing the preoperative plan is mainly related to the type of CAD software used and the learning curve for correctly elaborate the 3D data. The cost is mostly associated with the stereolithography modelling and guide prototyping. When considering the cost-benefit of computer assisted surgery, animal with complex deformities may be the best candidates for these advanced techniques.

The correction of biplane antebrachial deformities requires a detailed planning to localize and quantify the malalignment and to limit the complication rate [2,7]. It may be not feasible to accurately evaluate such complex bone deformities neither with a 2D radiographic study nor CT [4,10]. Furthermore, as extensively demonstrated in human medicine (REF computer assisted vs free-hand), computer assisted-surgeries could be more accurate and faster than free-hand techniques when performing osteotomy [13] fracture fixation [17], joint replacement surgery [11] and vertebral screw placement as well [5].

With regard to torsional correction, several papers reported the use of reduction guides, which allow for achieving a precise reduction of bone fragments [9,10]. These devices are designed to have the proximal K-wire holes not aligned with the distal holes. As a result, a correction of a torsional deformity is achieved by aligning the K-wires after the completion of the osteotomy.

In this study, we didn't diagnose a severe external torsion of the distal antebrachium and thus we opted for a visual alignment of the carpus to the elbow, before the final bone reduction. The use of joint-oriented K-wire could have been an efficient strategy for performing a more controlled correction of the torsional deformity. Alternatively, an external circular or hybrid fixator could have represented a useful surgical option for either osteotomy reduction or fixation of bone fragments.

In conclusion, we reported the prototyping and surgical application of patient-specific osteotomy guides, which allowed for a deformity correction that led to a successful clinical outcome. The reestablishment of a more physiological alignment of the antebrachium and carpus loading might limit the development of osteoarthritis in the medium-long term, thus decreasing chronic pain. Rehearsal surgeries and custom-made osteotomy guides represent favorable solutions for surgeons, who are challenged by the treatment of complex corrective osteotomies. In our experience, the surgically assisted correction of the angular limb deformity was straightforward compared to standard osteotomy and reduction technique.

References

1. Crosse, K.R., Worth, A.J., 2010, Computer-assisted surgical correction of an antebrachial deformity in a dog. Vet Comp Orthop Traumatol 23, 354–361.
2. Deruddere, K.J., Snelling, S.R., 2014, A retrospective review of antebrachial angular and rotational limb deformity correction in dogs using intraoperative alignment and type 1b external fixation. New Zeal Vet J 62, 290–296.
3. Dismukes, D.I., Fox, D.B., Tomlinson, J.L., Essman, S.C., 2008, Use of radiographic measures and three-dimensional computed tomographic imaging in surgical correction of an antebrachial deformity in a dog. J Am Vet Med Assoc 232, 68–73.
4. Dobbe, J., du Prè, K.J., Kloen, P., Blankevoort, L, Streekstra, G.J., 2011, Computer-assisted and patient-specific 3-D planning and evaluation of a single-cut rotational osteotomy for complex long-bone deformity. Med Biol Eng Comput 49, 1363-1370.

5. Farshad, M., Betz, M., Farshad-Amacker, N.A., Moser, M., 2017, Accuracy of patient-specific template-guided vs. free-hand fluoroscopically controlled pedicle screw placement in the thoracic and lumbar spine: a randomized cadaveric study. Eur Spine J 26, 738-749.
6. Fox, D.B., Tomlinson, J.L, Cook, J.L., Breshears, L.M., 2006, Principles of uniapical and biapical radial deformity correction using dome osteotomies and the center of rotation of angulation methodology in dogs. Vet Surg 35, 67-77.
7. Franklin, S.P., Dover, R.K., Andrade, N., Rosselli, D., 2017, Correction of antebrachial angulation-rotation deformities in dogs with oblique plane inclined osteotomies. Vet Surg 46, 1078- 1085.
8. Longo, F., Nicetto, T., Banzato, T., Savio, G., Drigo, M., Meneghello, R., Concheri, G., Isola, M., 2018, Automated computation of femoral angles in dogs from three-dimensional computed tomography reconstructions: Comparison with manual techniques. Vet J 232, 6-12.
9. Miyake, J., Murase, T., Oka, K., Moritomo, H., Sugamoto, K., Yoshikawa, H., 2012, Computer-Assisted Corrective Osteotomy for Malunited Diaphyseal Forearm Fractures. J Bone Joint Surg Am 94, 150-155.
10. Murase, T., Oka, K., Moritomo, H., Goto, A., Yoshikawa., H., Sugamoto, K., 2008, Three-dimensional corrective osteotomy of malunited fractures of the upper extremity with use of a computer simulation system. J Bone Joint Surg Am. 90, 2375-89.
11. Nakahara, I., Kyo, T., Kuroda, Y., Miki, H., 2018, Effect of improved navigation performance on the accuracy of implant placement in total hip arthroplasty with a CT-based navigation system. J Artif Organs 21, 340-347.
12. Oka, K., Moritomo, H., Goto, A., Sugamoto, K., Yoshikawa., H., Murase, T., 2008, Corrective osteotomy for malunited intra-articular fracture of the distal radius using a custom-made surgical guide based on three-dimensional computer simulation: case report. J Hand Surg 33, 835– 840.

13. Omori, S., Murase, T., Oka, K., Kawanishi, Y., Oura, K., Tanaka, H., Yoshikawa, H., 2015, Postoperative accuracy analysis of three-dimensional corrective osteotomy for cubitus varus deformity with a custom-made surgical guide based on computer simulation. J Shoulder Elbow Surg 24, 242-249.
14. Oxley, B., Gemmill, T.J., Pink, J., Clarke, S., Parry, A., Baines, S., McKee, W.M., 2013, Precision of a novel computed tomographic method for quantification of femoral varus in dogs and an assessment of the effect of femoral malpositioning. Vet Surg 42, 751–758.
15. Paley, D.: Frontal plane mechanical and anatomic axis planning. In: Paley, D., Herzenberg (eds): Principles of Deformity Correction, Springer-Verlag Berlin Heidelberg GmbH, New York, USA, 2003: 61-97.
16. Savio, G., Baroni, T., Concheri, G., Baroni, G., Meneghello, R., Longo, F., Isola, M., 2016, Computation of femoral canine morphometric parameters in three- dimensional geometrical models. Vet Surg 45, 987–995.
17. Wang, Y., Han, B., Shi, Z., Fu, Y., Ye, Y., Jing, J., Li, J., 2018, Comparison of free-hand fluoroscopic guidance and electromagnetic navigation in distal locking of tibia intramedullary nails. Medicine 27, 1-7.

Figure legends

Fig. 1: Orthogonal radiographic studies of case 1 (upper line) and case 2 (lower line). Craniocaudal and mediolateral radiographic projections showing a biplane antebrachial bone deformity (a and d). On the craniocaudal projection, the presence of a valgus deformity was observed. A severe lateral subluxation of the radius head was also noticed in case 2 (d). A cranial bowing of the radius and a distal antebrachial torsion were detected on the mediolateral projection. Images (b and e) depict immediate postoperative radiographs. The craniocaudal and mediolateral projections show the correction of the radius valgus and procurvatum as well as the presence of an ulnar ostectomy. A double plating technique with hybrid locking implants was used. Images (c) and (f) show the 12-weeks radiographic recheck. A complete bone healing at the level of radius osteotomy was detected. On image (c) a loosening of the proximal locking screw of the smaller plate (c) was found.

Another proximal locking screw of the same implant was previously removed at 8-weeks recheck. Image (f) shows that 3 screws were removed from the craniolateral plate following the detection of an increased radiolucency close to screws.

Fig. 2: Computer assisted preoperative planning. A closing bone wedge was created in the bone model to correct frontal and sagittal deformities. The ostectomized bones were manipulated to reach a new alignment (red and green bone models). The post-corrective antebrachial alignment was compared to the pre-corrective alignment (blue and purple bone models) by means of mirror image function. Red arrows indicate (a) the translation of the distal antebrachium on the sagittal plane.

Fig. 3: Three-dimensional printed patient-specific osteotomy guides. Image (a) shows the temporary fixation of the osteotomy guide. Image (b) shows the design and simulated application of the osteotomy guide onto the radial surface. The distal medial edge of the osteotomy guide was planned to anatomically match the profile of the medial ridge of the radius groove.

Fig. 4: Intraoperative images of case 1. Temporary fixation of the osteotomy guide with four K-wires (a). Execution of the radius closing wedge ostectomy (b): the osteotomy guide slits support the drill blade and guide the osteotomy. Anatomical bone reduction: a new antebrachial alignment was achieved (c). Radial double plate fixation using pre-contoured locking implants (d).